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(54) A filter circuit and a superconducting filter circuit

(57) A filter circuit includes a first resonator (15) and a second resonator (16) each having a different resonance frequency (f_1, f_2). The first resonator (15) is included in a first block (101), and the second resonator (16) is included in a second block (102). The first block (101) further includes a first delay unit (18) connected to the first resonator (15). An input terminal (11) divides an input signal to the first block (101) and the second block (102). An output terminal (12) combines signals passing through the first block (101) and the second block (102) and outputs the combined signal. The first delay unit (18) converts a phase difference between the signals passing through the first block (101) and the second block (102) to reverse-phase or nearly reverse-phase.

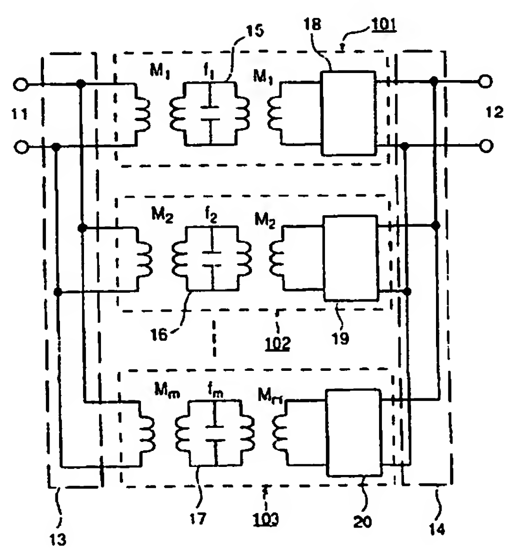


FIG. 4

EP 1 148 576 A2

second block to reverse-phase or nearly reverse-phase.

[0012] Further in accordance with the present invention, there is also provided a superconducting filter circuit, comprising: a first resonator and a second resonator each having a different resonance frequency, a first block including the first resonator having a superconcuctive material and a second block including the second resonator having a superconductive material, wherein the first block includes a delay unit connected to the first resonator; an input terminal configured to divide an input signal to the first block and the second block; and an output terminal configured to combine signals passing through the first block and the second block, and to output the combined signal; wherein said delay unit converts a phase difference between the signals passing through the first block and the second block to reverse-phase or nearly reverse-phase.

[0013] Further in accordance with the present invention, there is also provided a filter circuit, comprising: a first resonator and a second resonator each having a variable resonance frequency, a first block including the first resonator and a second block including the second resonator, wherein the first block includes a delay unit connected to the first resonator; an input terminal configured to divide an input signal to the first block and the second block; and an output terminal configured to combine signals passing through the first block and the second block, and to output the combined signal; wherein the resonance frequency of at least one of the first resonator and the second resonator is varied by an external control signal.

[0014] Further in accordance with the present invention, there is also provided a superconducting filter circuit, comprising: a first resonator and a second resonator each having a variable resonance frequency, a first block including the first resonator and a second block including the second resonator, wherein the first block includes a delay unit connected to the first resonator; an input terminal configured to divide an input signal to the first block and the second block; and an output terminal configured to combine signals passing through the first block and the second block, and to output the combined signal; wherein the resonance frequency of at least one of the first resonator and the second resonator is varied by control signal from external.

[0015] Fig. 1 is a block diagram of a resonator.

[0016] Fig. 2 is an example of the circuit shown in Fig. 1 using microstrip lines.

[0017] Fig. 3 is a schematic diagram of electric force lines in the component shown in Fig. 2.

[0018] Fig. 4 is a block diagram of a filter circuit according to a first embodiment of the present invention.

[0019] Fig. 5 is a waveform diagram of frequency response from input terminal 11 to output terminal 12 in Fig. 4.

[0020] Fig. 6 is a block diagram explaining the operation of the filter circuit shown in Fig. 4.

[0021] Fig. 7 is another block diagram explaining the operation of the filter circuit shown in Fig. 4.

[0022] Fig. 8 is a waveform diagram of frequency response in case of reverse-phase in Fig. 6.

[0023] Fig. 9 is a waveform diagram of frequency response in case of equal-phase in Fig. 6.

[0024] Fig. 10 is an example of the filter circuit shown in Fig. 4.

[0025] Fig. 11 is another example of the filter circuit shown in Fig. 4.

[0026] Fig. 12 is a modification example of the filter circuit shown in Fig. 10.

[0027] Fig. 13 is another modification example of the filter circuit shown in Fig. 10.

[0028] Fig. 14 is a modification example of the filter circuit shown in Fig. 11.

[0029] Fig. 15 is another modification example of the filter circuit shown in Fig. 11.

[0030] Fig. 16 is a block diagram of the first modification of the filter circuit shown in Fig. 4.

[0031] Fig. 17 is an example of the filter circuit shown in Fig. 16 using microstrip lines.

[0032] Fig. 18 is a block diagram of a second modification of the filter circuit shown in Fig. 4.

[0033] Fig. 19 is a block diagram of a third modification of the filter circuit shown in Fig. 4.

[0034] Fig. 20 is a waveform diagram of frequency response of the filter circuit shown in Fig. 19.

[0035] Fig. 21 is a block diagram of a fourth modification of the filter circuit shown in Fig. 4.

[0036] Fig. 22 is a block diagram of the filter circuit according to a second embodiment of the present invention.

[0037] Fig. 23 is a waveform diagram of frequency response of the first setting in the filter circuit shown in Fig. 22.

[0038] Fig. 24 is a waveform diagram of frequency response of the second setting in the filter circuit shown in Fig. 22.

[0039] Fig. 25 is a waveform diagram of frequency response of the third setting in the filter circuit shown in Fig. 22.

[0040] Fig. 26 is an example of the filter circuit shown in Fig. 22 by the microstrip line.

[0041] Fig. 27 is a sectional plane of the example of the filter circuit shown in Fig. 26.

[0042] Hereinafter, embodiments of the present invention are explained below with reference to the drawings. Fig. 4 is a block diagram of a filter circuit according to a first embodiment of the present invention. A resonator 15 having a resonance frequency f1 and a cascade connected delay unit 18 form a first block 101. In the same way, a resonator 16 having a resonance frequency f2 and a cascade connected delay unit 19 form a second block 102. A resonator 17 having a resonance frequency fm and a cascade connected delay unit 20 form a third block 103.

[0043] In Fig. 4, the filter circuit includes an input terminal 11, an output terminal 12, an electric power division unit 13 as parallel-connection part of the input terminal 11, an electric power combination unit 14 as parallel-connection part of the output terminal 12, and the first, second, and third blocks 101~103 each connected in parallel between the

f2 is controlled as ripple value in desirable filter waveform by suitably setting the frequency interval between f1 and f2 and the mutual coupling degrees M1 and M2 between the resonators 15 and 16. For example, if the ripple value is set below 3dB, the frequency response includes a pass-characteristic between response frequency band fl ~f2. In order to set the ripple value below 3dB, the phase difference between the first block 101 and the second block 102 is set within the limit (-30° ~+30°) from reverse-phase (180°) as shown in equation (2).

[0051] Furthermore, if the delay unit 18 cascaded to the resonator 15 having the resonance frequency f1 and the delay unit 19 cascaded to the resonator 16 having the resonance frequency f2 are related as the phase difference of "(360° × n)±30° (n ≧ 0: integer)", the resonance frequencies of the first block 101 and the second block 102 are regarded as nearly equal-phase. Fig. 9 is a waveform diagram of frequency response in case of equal-phase in Fig. 6. As shown in Fig. 9, if the phase difference between two delay units 18, 19 satisfies the limit "(360° × n)±30° (n ≧ 0: integer)", the characteristic curved line 51 of the filter circuit is calculated as a difference between the characteristic curved line 52 of the frequency response of the resonator 15 and the characteristic curved line 53 of the frequency response of the resonator 16. The control of ripple value by mutual coupling degree has a limit. Accordingly, in case of nearly equal-phase, the characteristic curved line 51 does not include the pass-characteristic in the resonance frequency band f1~f2.

[0052] By designing the circuit component shown in Figs. 4 and 6, the pass-electric power is divided to each resonator. Accordingly, in comparison with the past cascade connected resonators, the characteristic of maximum available power is superior. This feature also improves a filter circuit of microstrip line type using superconductors. By using small-sized filters of microstrip line type, the filter circuit having maximum available power above several-watt is realized.

[0053] Component examples of a filter circuit of the microstrip line type of the first embodiment are shown in Figs. 10 and 11. Fig. 10 shows the filter circuit of end-couple type and Fig. 11 shows the filter circuit of side-couple type. In Fig. 10, an input terminal 61, an output terminal 62, an electric power division means 63, and an electric power combination means 64 are formed on a main face of a dielectric substrate 60. On the other side of the dielectric substrate 60 (relative dielectric constant ε r = 24), a ground metal is formed (not shown in Fig. 10). The resonator in Fig. 4 corresponds to microstrip conductors 65, 66, 67 of half-wave length of the designable frequency and circumferential dielectric (the dielectric substrate 60 and exposed part (air)). The delay unit in Fig. 4 corresponds to microstrip conductors 68, 69, 70 each including half-wave length between adjacent lines (68 and 69, 69 and 70). By this component, the resonator 66 having the resonance frequency f2 includes the phase difference "180 ° " for the resonator 65 having the resonance frequency f1 and the resonator 67 having the resonance frequency f3. Furthermore, the electric power from the input terminal 61 is supplied to each resonator 65, 66, 67 by the electric power division means 63. The divided electric power through three resonators 65, 66, 67 is combined by the electric power combination means 64 and is connected to the output terminal 62. In this case, the electric power combination means 64 is represented as a joint point of microstrip conductors 68, 69, 70. In the example of Fig. 10 not equivalent circuit diagram as Fig. 4, the electric power combination means 64 and the output terminal 62 are regarded as the identical one. In the same way, the electric power division means 63 and the input terminal 61 are regarded as the identical one.

[0054] In Fig. 10, in case that the designable frequency band is 2 GHz, the width of all microstrip conductor is 0.2mm, the length of microstrip conductor 65 is 20.02mm, the length of microstrip conductor 66 is 20.10mm, the length of microstrip conductor 67 is 20.18mm, the length of microstrip conductor 68 is 20mm, and the length of microstrip conductor 70 is 20mm. Furthermore, as material of the microstrip conductor one or more of Cu, Ag, Au, superconductor (YBCO), are preferably utilized. As material of the dielectric substrate one or more of sapphire, alumina, $LaAlO_3$, MgO, $SrTiO_3$, are preferably utilized.

[0055] In case that impedance matching is set at a branch point of the electric power division means and the electric power combination means, the width of the microstrip conductor is varied as shown in Fig. 11. In this case, while the width of the microstrip conductor of the resonator and the delay unit is 0.2mm in the same way as in Fig. 10, the width of microstrip conductor of the input terminal 71 and the output terminal 72 is 0.8mm. The length of microstrip conductor 75 is 20.02mm, the length of microstrip conductor 76 is 20.10mm, and the length of microstrip conductor 78 is 20mm.

[0056] In Fig. 11, the resonators 75, 76 of half-wave length are utilized as the resonator, and transmission lines 78, 79 including half-wave length between adjacent lines are utilized as the delay unit. By using these components, the resonator 76 having the resonance frequency f2 is realized as the phase difference 180° for the resonator 75 having the resonance frequency fl. The electric power from the input terminal 71 is supplied to each resonator 75, 76 by the electric power division means 73. The divided electric power through two resonators 75, 76 is combined by the electric power combination means 74 and output from the output terminal 72.

[0057] Fig. 12 shows a modification example of Fig. 10. Instead of the delay unit 68 in Fig. 10, a meandering line is used as the delay unit 81. By using this meandering line, a large delay value can be realized. Furthermore, if order of height of resonance frequency of each resonator 65, 66, 67 including a microstrip conductor satisfies the delay difference condition of equation (2), the resonance frequency of each resonator may be assigned in an arbitrary order.

[0058] Fig. 13 is a modification example of Fig. 10 as the filter circuit of a coplanar line. As for the same reference numbers in Fig. 10, the explanation in Fig. 13 is omitted by referring to the above-mentioned explanation of Fig. 10.

For example, a phase difference between adjacent resonance frequencies (f2, f3) of two resonators is set as nearly equal-phase "(360° × n)±30° " by the delay unit of the two resonators, and three resonance frequencies (f2, f3, f4) of three resonators are controlled below 10% of pass-band of resonator level by the control signal. In this case, waveforms of the two adjacent resonance frequencies (f2, f3) of equal-phase cancel each other, and the resonance frequency (f4) is further overlapped. As a result, waveforms of the resonance frequencies (f2, f3, f4) form one waveform 613. As for other resonance frequencies except for the resonance frequency (f2, f3, f4), in the same way as the first setting, a phase difference between every two adjacent resonance frequencies of two blocks is represented by the equation (2) as shown in waveforms 612, 614. The waveform 611 represents the frequency response from the input terminal 11 to the output terminal 12. Thus, the control apparatus 411 in Fig. 22 controls three resonance frequencies (f2, f3, f4) to overlap as shown in the waveform 613 of Fig. 24. As a result, the pass-band of the filter circuit is transformed toward narrower direction on the frequency axis.

[0070] Fig. 25 shows frequency response characteristic in case of the third setting in the filter circuit of Fig. 22. As the third setting, in the same way as the second setting, the pass-band of the filter circuit is controlled toward a narrower direction on the frequency axis. For example, a phase difference between two separated resonance frequencies (f2, f4) of two resonators is set as nearly equal-phase by the delay unit of the two resonators, and the two resonance frequencies (f2, f4) of the two resonators are controlled below 10% of pass-band of resonator level by the control signal. In this case, waveforms of the two resonance frequencies (f2, f4) cancel each other, and the effect of the resonance waveform of the resonance frequencies (f2, f4) can be reduced as shown in waveform 623. As for other resonance frequencies except for the resonance frequency (f2, f4), in the same way as in the first setting, a phase difference between every two adjacent resonance frequencies of two blocks is represented by the equation (2) as shown in waveforms 622, 624, 625. The waveform 621 represents the frequency response from the input terminal 11 to the output terminal 12. Thus, the number of resonance frequencies that contributed to the frequency response is reduced and the pass-band of the filter circuit is transformed toward the narrower direction on the frequency axis.

[0071] As shown in Fig. 1, in order to vary the center frequency and the pass band in the filter circuit in which n units of resonators are cascaded, control of (2n+1) units of the resonance frequency (n units), the external Q (2 units), and the coupling factor ((n-1) units) for each resonator is necessary. However, in the second embodiment, the pass-band is varied by controlling the resonance frequency of each resonator, i.e., by n units of control. Furthermore, in the past, (2n+1) units of control signal lines from the control apparatus are necessary. However, in the second embodiment, only n units of control signal lines are only necessary.

[0072] As an application example of the second embodiment, a filter circuit using a superconducting conductor is utilized as a base station. This filter circuit must be packaged in a refrigerator because the superconducting conductor is used. In comparison with the prior art, heat-penetration from the control signal lines to the refrigerator is reduced and it is possible that the base station is driven in a small-sized refrigerator. Furthermore, in the same way as in the first embodiment, any resonator of the distributed element circuit and the lumped element circuit such as a half-wave length resonator of microstrip line type can consist of the filter circuit.

[0073] Figs. 26 and 27 show an example of a half-wave length resonator of the microstrip line type. Fig. 26 is a plan view corresponding to Fig. 10 (a dielectric film 714 and a voltage impressed element 715 are omitted). Fig. 27 is a sectional plan view neighboring the resonator 711. The resonator 711 in Fig. 27 corresponds to conductors 705, 706, 707 in Fig. 26.

[0074] One surface of the conductors formed on both surfaces of the dielectric is patterned as the resonator 711. The relative permittivity of dielectric film 714 is varied by an impressed voltage and is laid over the resonator 711. The voltage impressed element 715 (material is $SrRuO_3$) is located on the dielectric film 714. As representative material for the dielectric substrate 713, MgO, $SrTiO_3$, $LaAlO_3$, are selectively utilized. Furthermore, by utilizing a superconducting conductor as the conductor 711 and the ground metal 712, the filter circuit of characteristic of great low loss can be realized. As representative material of the superconducting conductor, an oxide such as yttrium, bismuth, thallium, and NbSn are well known. As the patterning method, MOCVD method, sputtering method, laser ablation method, liquid deposition method are selectively used. Furthermore, as material of the dielectric film 714 of which relative permittivity is varied by impressed voltage, a ferroelectric substance such as $SrTiO_3$, $Ba_xSr_{1-x}TiO_3$, is well known. When the voltage is impressed to the voltage impressed element 715 by the control signal from the control apparatus 411 in Fig. 22, the relative permittivity of the dielectric film 714 on the resonator 711 varies, and the resonance frequency varies by varying the propagation constant of the resonator 711. As one method for patterning this filter circuit, the conductor is attached on both surfaces of the dielectric substrate by a laser ablation method, and the one surface is patterned as the layout shown in Fig. 26. Then, the dielectric film 714 is attached on the one surface by the laser ablation method. Last, the voltage impressed element 714 is patterned as electrode by the sputtering method. In this way, the filter circuit is manufactured.

[0075] In the above-mentioned explanation, the voltage impressed element 715 is located on the conductors 705, 706, 707 for the resonator. However, the second embodiment is not limited to this patterning. The voltage impressed element 715 may be located on other conductors (the input terminal 701, the output terminal 702, the delay unit 704)

wherein at least one block includes a plurality of resonators cascaded, in accordance with a distribution of pass-electric power of the one block in all blocks.

10. The filter circuit according to claim 1,
wherein the first resonator and the second resonator comprise microstrip lines.

11. The filter circuit according to claim 1,
wherein the first resonator and the second resonator comprise a coplanar line.

12. The filter circuit according to claim 1,
wherein the first resonator and the second resonator comprise a lumped element circuit.

13. A superconducting filter circuit, comprising:

a first resonator and a second resonator each having a different resonance frequency, a first block including the first resonator having a superconductive material, and a second block including the second resonator having a superconductive material, wherein the first block includes a delay unit connected to the first resonator;
an input terminal configured to divide an input signal to the first block and the second block; and
an output terminal configured to combine signals passing through the first block and the second block, and to output the combined signal;
wherein said delay unit converts a phase difference between the signals passing through the first block and the second block to reverse-phase or nearly reverse-phase.

14. A filter circuit, comprising:

a first resonator and a second resonator each having a variable resonance frequency, a first block including the first resonator and a second block including the second resonator, wherein the first block includes a delay unit connected to the first resonator;
an input terminal configured to divide an input signal to the first block and the second block; and
an output terminal configured to combine signals passing through the first block and the second block, and to output the combined signal;
wherein the resonance frequency of at least one of the first resonator and the second resonator is varied by an external control signal.

15. The filter circuit according to claim 14,
wherein said delay unit converts a phase difference between the signals passing through the first block and the second block to reverse-phase or nearly reverse-phase.

16. The filter circuit according to claim 15,

further comprising a third block including one resonator, each resonance frequency of all blocks including the first block and the second block is independently variable, at least one of every two blocks having the closest two resonance frequencies on frequency axis includes one delay unit,
wherein the delay unit converts a phase difference between signals passing through the two blocks to reverse-phase or nearly reverse-phase.

17. The filter circuit according to claim 16,
wherein each resonance frequency of all blocks is different.

18. The filter circuit according to claim 17,

wherein the delay unit of the two blocks converts a phase difference between signals passing through the two blocks to equal-phase or nearly equal-phase, and
wherein each resonance frequency of the two blocks and one block of which resonance frequency is closest to one of two resonance frequencies of the two blocks is set within 10% of a pass-band by the control signal.

19. The filter circuit according to claim 17,

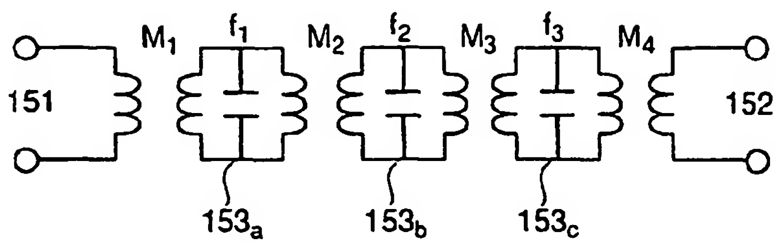


FIG. 1 (PRIOR ART)

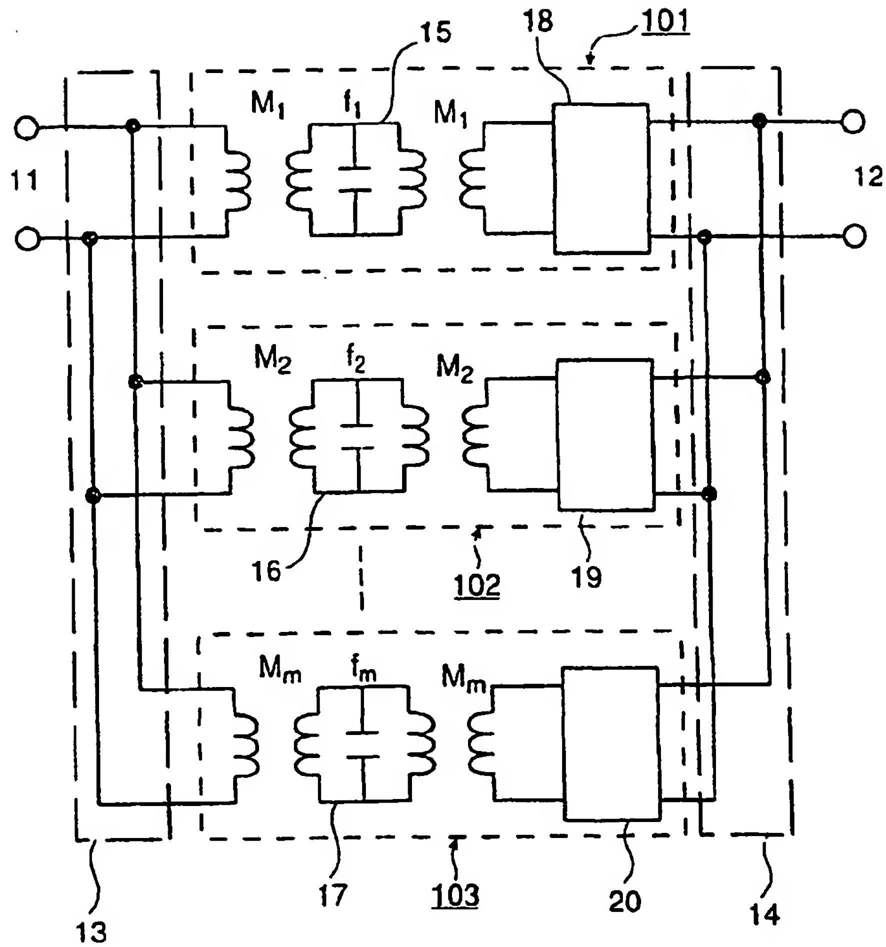


FIG. 4

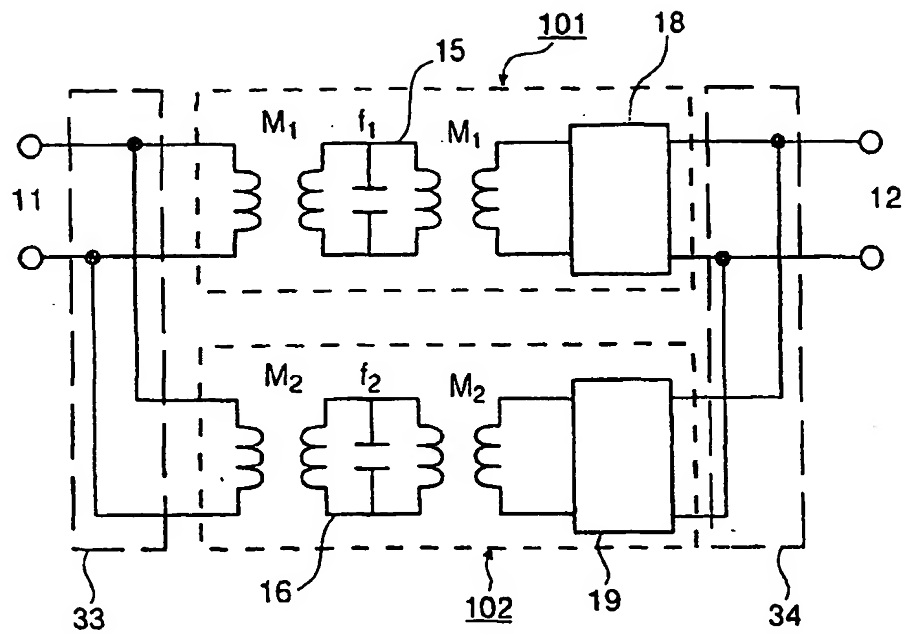


FIG. 6

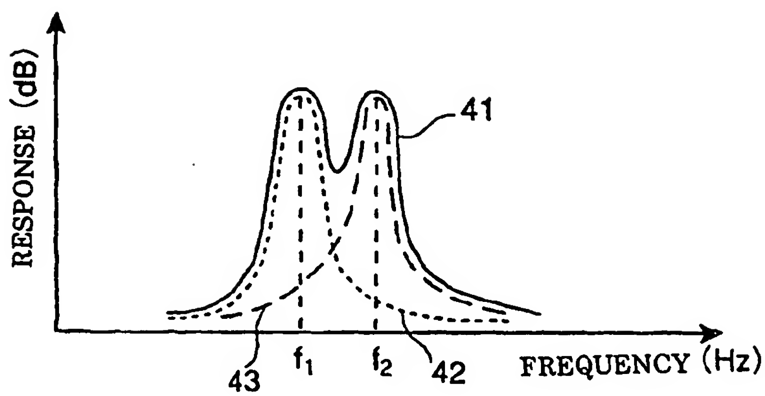

RESPONSE (dB)
41
43
f_1
f_2
42
FREQUENCY (Hz)

FIG. 8

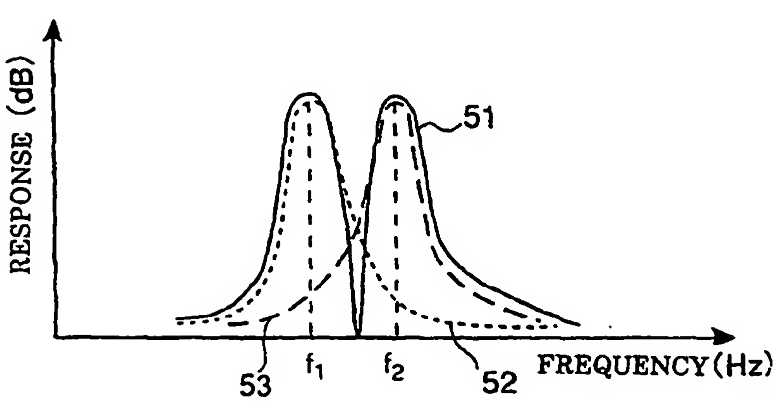

RESPONSE (dB)
51
53
f_1
f_2
52
FREQUENCY (Hz)

FIG. 9

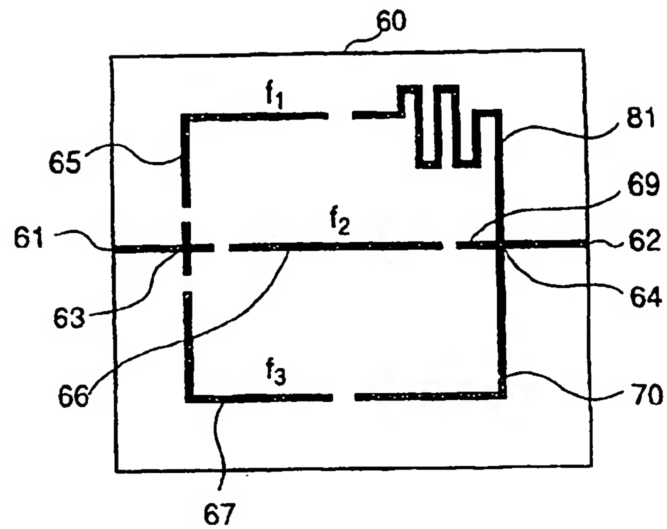

60
f1
81
65
69
f2
61
62
63
64
66
f3
70
67

FIG. 12

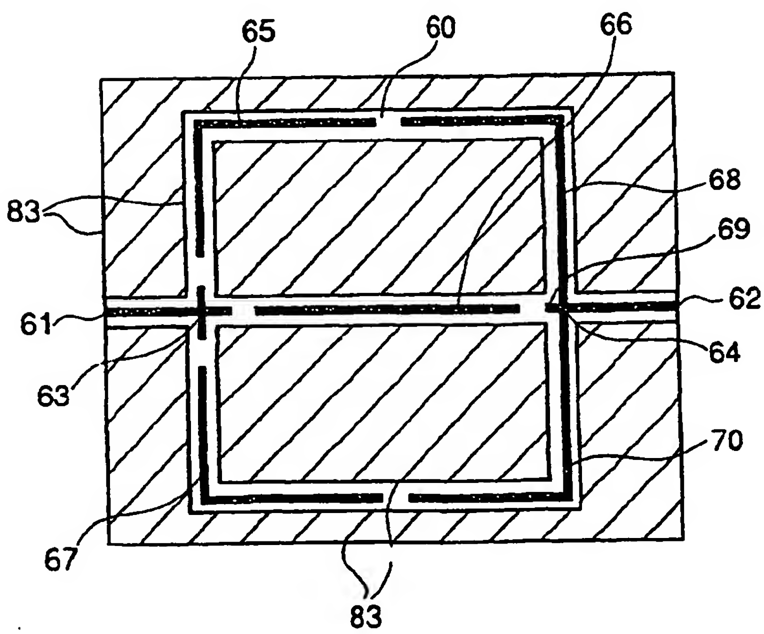

65
60
66
68
83
69
61
62
63
64
70
67
83

FIG. 13

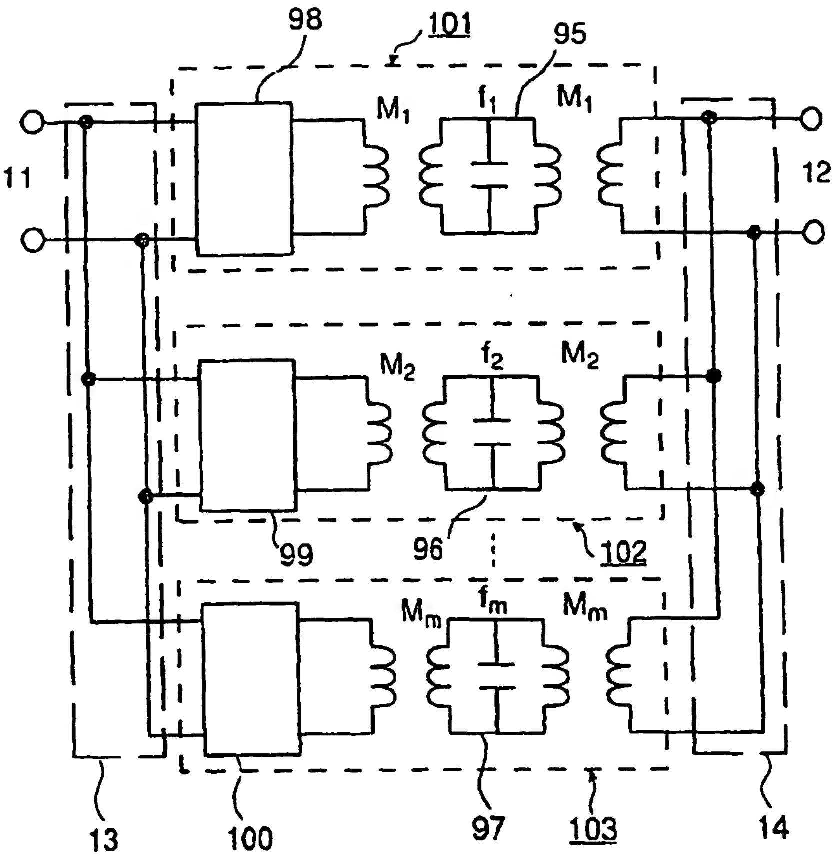
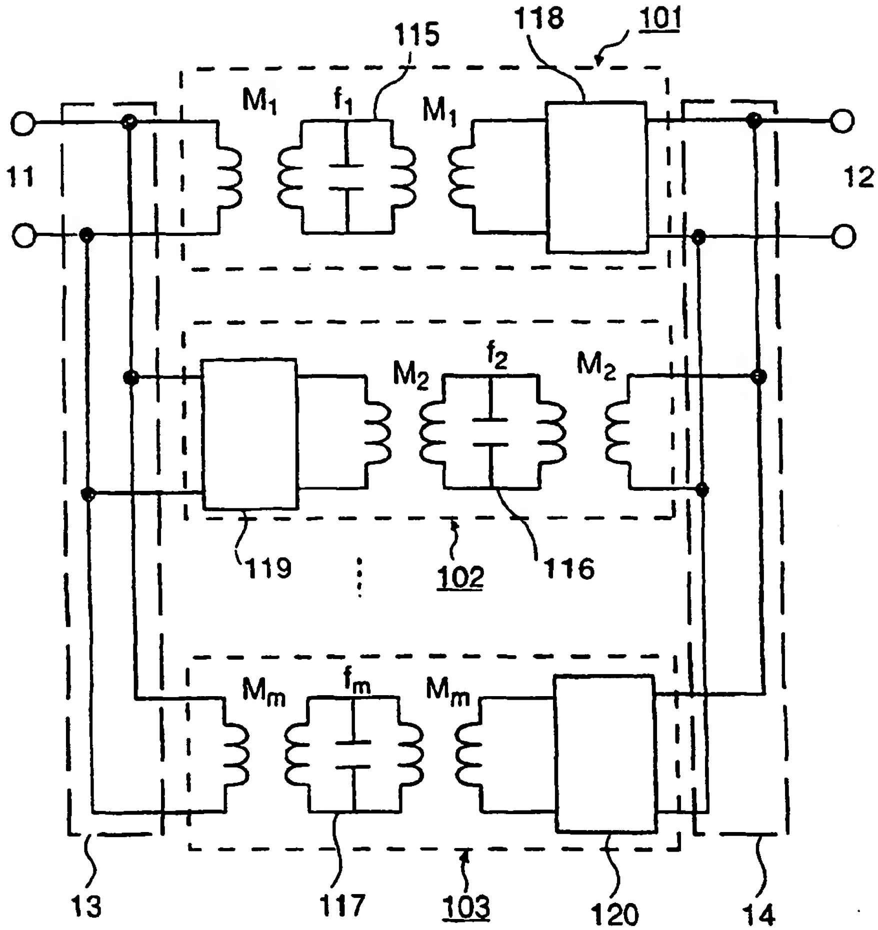


FIG. 16


115
118
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M_1
f_1
M_1
11
12
M_2
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13
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103
120
14

FIG. 1 8

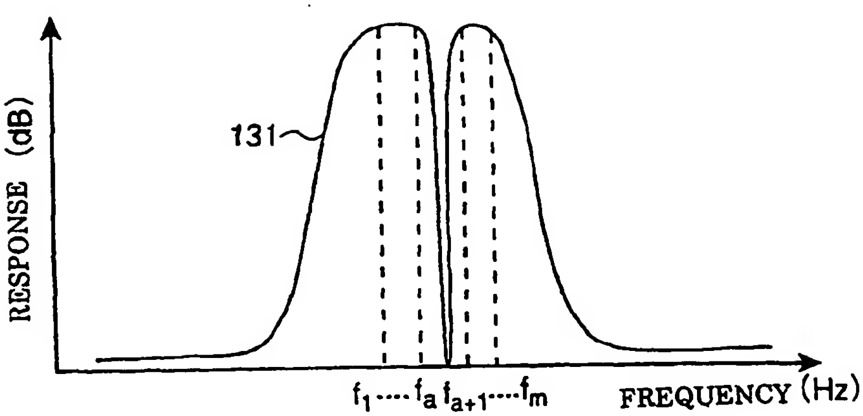

FIG. 20

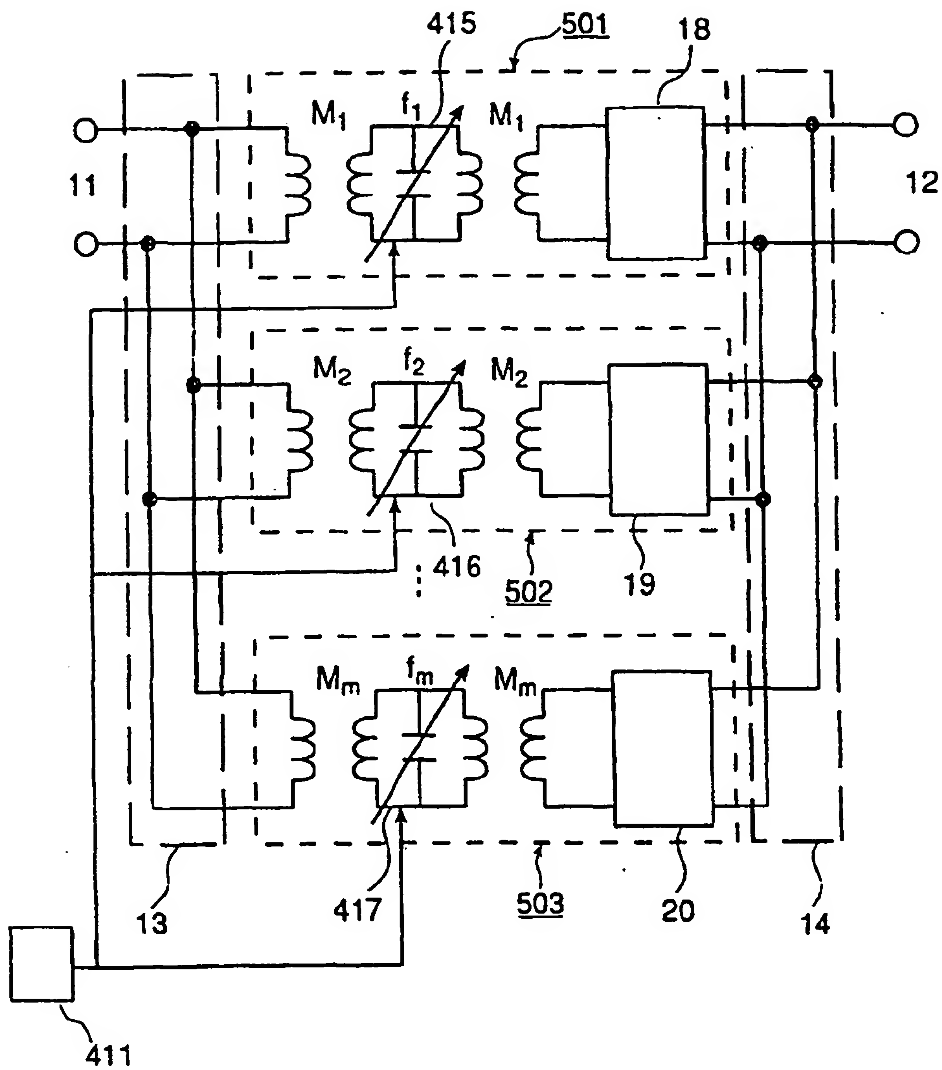
415
501
18
M_1
f_1
M_1
11
12
M_2
f_2
M_2
416
502
19
M_m
f_m
M_m
13
417
503
20
14
411

FIG. 22

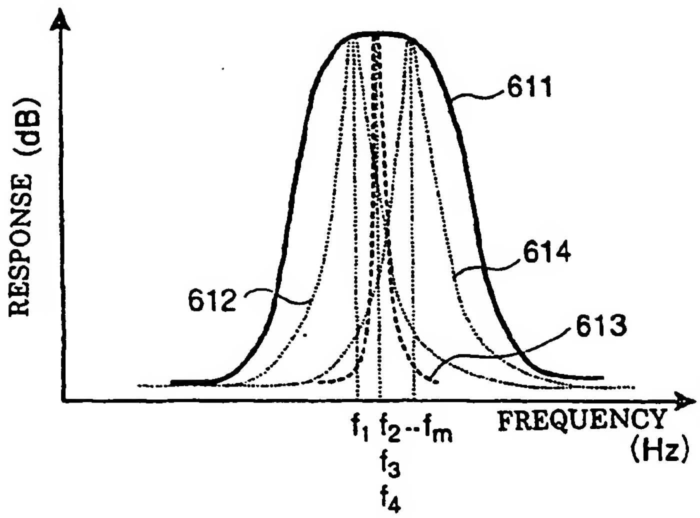

FIG. 2 4

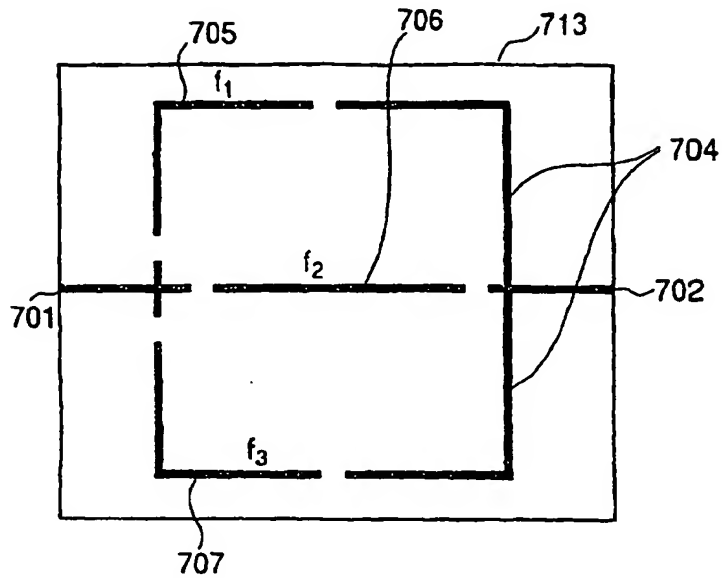

FIG. 26

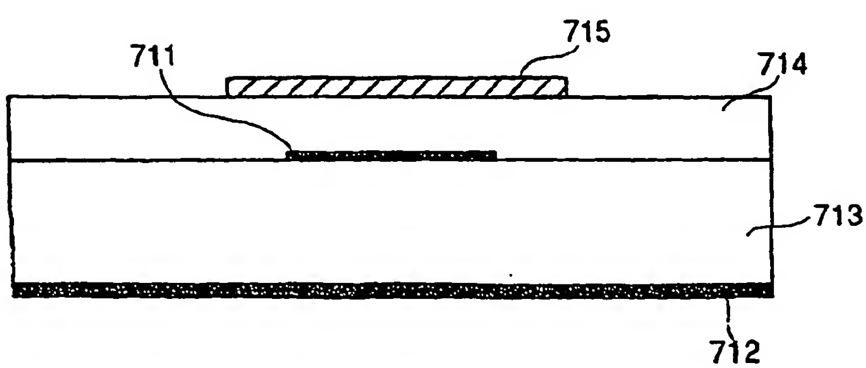

FIG. 27

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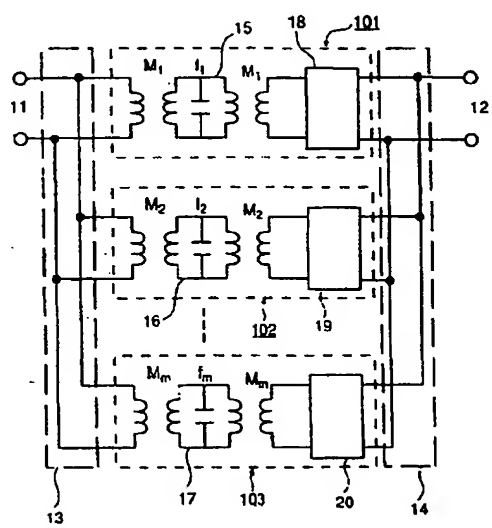

FIG. 4

EP 1 148 576 A3

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 01 30 2499

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